運用模糊分析層級程序法評估綠色供應商
Green Suppliers Assessment Using Fuzzy AHP

李正文
Cheng-Wen Lee

摘要

全球化壓力趨使多國籍企業更重視環境績效，特別針對科技密集產業。本研究提出綠色供應商評估層級架構，強調實質環保績效，研究方法採模糊分析層級程序法進行。以隨機方式取得研究樣本 28 位，為南非地區通訊機器製造商之部門經理。本研究的主要貢獻在於提供給決策者如何運用綠色供應鏈來提升環保績效。

關鍵詞：綠色供應商，環保績效，模糊分析層級程序法

Abstract

Globalization has resulted in pressure on multinational firms, especially in technology-intensive industries, to improve environmental performance. This study presents a hierarchical structure of green supplier assessment that addresses actual environmental performance using Fuzzy Analytical Hierarchy Process (AHP). Regarding the data collected, a random sample of 28 functional area managers was drawn from communication equipment manufacturing organizations located in South Africa. The major contribution of this research lies in its suggestions for how decision makers may improve environmental performance using green supply chains.

Keywords: green supplier, environmental performance, Fuzzy AHP

I. INTRODUCTION

South Africa (SA) is one of the most sophisticated and promising markets in the world, offering a unique combination of highly developed first world economic infrastructure with a vibrant emerging market economy. It is also one of the most advanced and productive economies in Africa. The survey ranked 155 countries according to the number of procedures, time and costs involved in: starting a business; dealing with licenses; hiring and firing workers; registering property; getting credit; protection for investors; paying taxes; trading across borders; enforcing contracts; and closing a business [1]. South Africa ranked 28th, ahead Spain (ranked at 30), Austria (32), France (44), Russia (79), China (91) and Brazil (119). Overall, SA had the highest ease-of-business ranking on the African continent. SA was the largest investor into the rest of Africa between 1990 and 2000, according to a 2003 report by LiquidAfrica Research, with investment averaging around USD1.4-billion, amounting to some USD12.5-billion over the decade.

The country's manufacturing output is becoming increasingly technology-intensive, with high-tech manufacturing sectors -- such as machinery, scientific equipment and motor vehicles -- enjoying a growing share of total manufacturing output since 1994. SA's technological research and quality standards are world-renowned. The country has developed a number of leading technologies, particularly in the fields of energy and fuels, steel production, deep-level mining, telecommunications and information technology. For example, UK-based global cellular group Vodafone is to use South Africa as one of three countries to launch its own-name brand of low-cost mobile handsets, aimed at ensuring easier access to telephony for millions of people in developing countries. China's ZTE Corporation is manufacturing the Vodafone 125 and the Vodafone 225, following an agreement between the two companies in late 2006, based on features, design and functionality specified by Vodafone.

On the other hand, however, globalization has resulted in pressure on multinational firms, especially in technology-intensive industries, to improve environmental performance. As a consequence of this pressure, and the efforts to address it, environmental management issues have become relevant to operations management researchers. Recently, new environmental regulations, such as European WEEE & RoHS, have stated. Besides, in SA, Non-governmental organization the Institute for Zero Waste (Izwa) has launched a national initiative to

中原大學國際貿易學系
*Corresponding author. E-mail: chengwen@cycu.edu.tw
Department of International Trade, Chung Yuan Christian University, Chung-Li, Taiwan, R.O.C.
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reduce the potential negative impacts of waste and pollution during the 2010 FIFA World Cup. The campaign, described as an attempt to "green the World Cup, African style," invites players involved in the World Cup to register with the Zero Waste 2010 Coalition "so that they may receive support in greening their operations well before 2010."

One potential path for achieving improvement in environmental performance, while maintaining production quality and cost goals at the plant level, is unique partnerships with suppliers [2]. Accordingly, green supply chain management (GSCM) in accord with environmental requirements, also becomes a hot topic for entrepreneurs and managers. In response, the main purpose of this paper is to explore the method of assessing the green suppliers--partners involved in innovating green eco-technology and enhancing environmental performance.

II. SUPPLY CHAIN

The popularity of the supply chain concept has origins in many areas: quality revolution [3], notions of materials management and integrated logistics [4], growing interest in industrial markets and networks [5] and influential industry-specific studies [6]. There are five supply improvement strategies on a supply chain model: (i) fine-tuning the existing decision rules, (ii) reducing time delays at and within each stage of the supply chain, (iii) eliminating the distribution stage from the supply chain, (iv) improving the decision rules at each stage of the supply chain, (v) integrating the flow of information and separating demands into "real" orders, which are true market demands, and "cover" orders, which are orders that bolster safety stocks [7].

A number of organizations and individuals within the specific (e.g., automobile industry) are already moving towards supply chain management through the use of partnering, framework agreements, and techniques to rationalize their supplier base [8]. It should be noted that if a supply chain does not demonstrate its attributes, then neither a concurrent engineering approach nor supply chain management efforts will deliver the benefits sought [9, 10].

The supply chain is regarded as an interconnected series of activities concerned with planning and controlling raw materials, components, and finished products from suppliers to the final consumer [11]. The supply chain is also recognized as the network of facilities and activities which perform the functions of product development, procurement of materials, movement of materials between facilities, manufacturing of goods, distribution of finished goods to customers, and after-market support [12].

A supply chain is an integrated manufacturing process wherein raw materials are converted into final products, then delivered to customers. At its highest level, a supply chain is comprised of two basic, integrated processes: (i) production planning and inventory control process, and (ii) distribution and logistics process [13]. The production planning and inventory control processes encompass the manufacturing and storage sub-processes and their interface(s). More specifically, production planning entails the design and management of the entire manufacturing process (including raw material scheduling and acquisition, manufacturing process design and scheduling, and material handling design and control).

Supply chain management covers the short- and long-term collaboration of a company with other companies to develop and manufacture products with the required internal and inter-company organization, planning and control of the flows of materials, financial value and information along the business processes [14, 15]. Combinations of business processes lead to supply chain networks in which materials, financial values and information are dispatched and exchanged in a manner which involves all participating companies [16]. "Environmental purchasing" is defined as consisting of purchasing involvement in activities that include reduction, reuse, and recycling materials [17]. Life cycle issues of the ultimate disposition of materials must be considered as constituting an integral part of the purchasing and procurement process [18]. "Green purchasing" or "environmental purchasing" is now well covered in the Logistics literature, and is becoming a key component of GSCM.

Accordingly, the business processes are not limited to the framework of procurement, production, distribution, reverse logistics and packing, but is extended to the operational functions of waste reduction, recycle, reproduce, reuse and disposal. This network is defined as extended supply chain network. Therefore, starting from customer-related strategies, the product and service program and the strategic targets for the individual business processes must be determined as essential tasks for the development of the supply chain network.

The six strategies are proposed for dealing with environmental issues, including resistant adaptation, embracing without innovating, and being reactive, receptive, constructive, and proactive [19]. Given mounting public perception that corporate responses to environmental challenges have been inadequate, there is a mandate to move beyond constructive strategies. Companies need to adopt proactive strategies that shape a new vision of their short- and long-term environmental responsibilities. Communication equipment firms worldwide likewise face increasing pressures in the environmental arena. Over the past decade, there has been a consistent trend toward the reduction of environmental releases in the automotive manufacturing sector.

Buyers'/manufacturers' relationships with suppliers are characterized by short-term contracts, arms-length relationships, and multiple suppliers per part [20]. To the present, researchers have shown evidence of a movement toward closer and more cooperative supplier-manufacturer relationships [21]. The close supplier-manufacturer relationships observed in Japan's auto industry are thought to be a key factor in the success of Japanese manufacturers, as they contributed to decreased development time, lowered costs, and increased product quality [22]. However, the extent of supplier involvement varies significantly between automotive companies [23]. Most manufacturers and customers are concerned about the environmental and safety impact generated by the use of products. While the major environmental impact that occurs during the life cycle of a product is generated during the use of the product itself, the environmental impact of manufacturing process is also of significance [24].

Companies often carry out the retail process for production companies. One main industry with interest in an extended supply chain management perspective is the communication equipment industry. Some communication equipment manufacturers originate from local small and medium enterprises (SMEs), but more have become global companies with global development, sourcing, manufacturing and selling. From 2007 onwards, communication equipment manufacturers are forced by European Union Law to recycle new products sold within the European Union. Therefore, these firms have a rising interest in optimizing their supply chain network from the development to recycling stages.

Accordingly, this paper explores the role of suppliers in green supply chain management and hence, employs an environmental viewpoint to explore the evaluation criteria and selection procedure of green suppliers assessment for decision-makers.

III. CRITERIA OF GREEN SUPPLIERS ASSESSMENT

JIT (just-in-time) programs with internal environmental management practices may cause further degradation of environmental performance [25]. Therefore, manufacturers should implement green supplier choice management (GSCM) programs in place of JIT programs, from an environmental perspective. The development of supplier evaluation systems that place significant weight on objective environmental criteria can play a major role in influencing supplier activities. Thus, companies include a past environmental track record in their criteria for selecting material suppliers [26].

Companies will thrive only when they act as whole systems including all stakeholders, and integrate total quality environmental management (TQEM) into their planning and operations [27]. TQEM indicates the company makes efforts at continuous environmental improvement through Total Quality Management programs. The improvements include: (i) waste water: these indices consist of total water consumption, some specific critical water wastes (COD, total nitrogen, phosphorous, dissolved salts) due to the supplier's plants; (ii) air emissions: these are related to a supplier's emissions of critical substances, such as SO_2, NH_3, CO_2, NH_x, HCI and organic gas; (iii) solid wastes: these express the total volume of solid wastes achieved by the supplier each year; (iv) energy consumption: such an indicator points out the supplier's total amount of energy consumption within the year. At the pre-qualification stage, clients should select suppliers complying with, or certified to, both ISO 9000 and ISO 14000 certifications [28]. The link between quality and environment is emphasized by the fact that ISO 14000 certification was modeled after its predecessor, the ISO 9000 quality certification [19]. Quality can be defined broadly. In this paper, we define it as two main activities: TQEM and ISO 14000 certification as sub-criteria of the "quality" indicator of environmental performance.

Decisions with respect to costs made at the designed and engineering stages have a significant impact on manufacturing and service costs, as well as the quality of the final product [29-31]. Environmental costs associated with life cycle stages potentially influence product design, operations and maintenance decisions, recycling, and reuse activities, as well as disposal methods termed the "life cycle (LC) cost" [32]. To define the life cycle cost of the supplied component, managers have to consider purchase costs and all other costs that the company must bear during the product life cycle. These are related to (i) costs for component disposal when they have been used to achieve the final product, but have been detected as defective within the company's plants; and (ii) costs for the disposal and/or recovery of the end-of-life components [33].

Increasing costs of cleaning coupled with advances in materials and process technology are now driving some companies to raise emphasis on environmental problems. For example, one of the most effective means for reducing emissions and hazardous wastes from automotive painting is to reduce the level and number of input chemicals through material substitution, such as water-borne and powder paints, leading to lower levels of pollutants for treatment or control. Accordingly, we use LC cost and Cleaning cost as sub-criteria of the "cost" indicator of environmental performance.

Response means to respond in time to any requirement, especially in environmental needs. Innovation refers to an evolution or revolution to support green products or processes. Innovation has the meaning of both the process of long-term and progressive change as well as including dynamic processes [34]. One of the benefits to automotive manufacturers acquired from stronger relationships with suppliers has been increased external information on and experience with different technologies [35]. Accordingly, we use Response and Innovation as sub-criteria of the "flexibility" indicator of environmental performance.

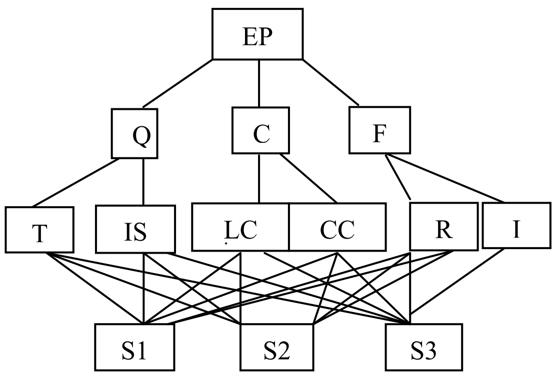
Overall, this paper establishes three main criteria and six sub-criteria for selecting the best and most appropriate supplier as shown in Fig. 1. These criteria are Quality (TQEM and ISO 14000 certification), Cost (LC cost and Cleaning cost), and Flexibility (Response and Innovation).

IV. SAMPLE

Regarding the data collected, a random sample of 28 functional area managers in communication equipment manufacturing organizations was drawn from the database of press releases related to Africa -- The African Press Organisation. A survey was conducted among a sample of five business scopes including 8 audio communication engine, 6 communication cable assemblies, 6 dot-matrix phone display, 5 microwave devices and 3 telepower technology. Each manager was contacted by telephone and requested to take part in the study. On agreeing to do so, each manager was interviewed within July-Oct, 2006. The average age of responding managers was 38 year olds, the mean years of experience in the areas they managed was 6.2. They had held their present position for average of four years and the number of employees in their areas of responsibility was more than 60.

V. FUZZY ANALYSIS HIERARCHY PROCESS

As noted above, environmental performance is a very important managerial issue for an organization. Within a green supply chain, the supplier plays a significant role in improving its automaker's environmental performance. Therefore, the next step of this study is to examine the key criteria for assessing the green supplier. In so doing, the second methodology used for this approach was the Fuzzy Analytical Hierarchy Process (AHP).



Note: Environmental Performance(EP)
Quality (Q)
Cost (C)
Flexibility (F)
TQEM (T)
ISO 14000 Certification (IS)
Life Cycle Cost (LC)
Cleaning Cost (CC)
Response (R)
Innovation (I)
Supplier 1 (S1)
Supplier 2 (S2)
Supplier 2 (S3)

Fig. 1 The hierarchical structure of green suppliers assessment

The standard AHP divides the decision problem into the following main steps: (i) problem structuring; (ii) assessment of local priorities; and (iii) calculation of global priorities [36]. The AHP decision problem is structured hierarchically at different levels, each level consisting of a finite number of decision elements. The top level of the hierarchy represents the overall objective/focus of the problem, while the lowest level is composed of all possible alternatives. One or more intermediate levels embody the decision criteria and sub-criteria. The relative importance of decision elements (weights of criteria and scores of alternatives) is assessed indirectly from comparison judgments during the second step of decision process. The decision-maker is required to provide his/her preferences by comparing all criteria, sub-criteria and alternatives with respect to upper level decision elements. The values of the weights and scores are elicited from these comparisons and represented in a decision table. The last step of the AHP aggregates all local priorities from the decision table by a simple weighted sum. The global priorities thus obtained are used for final ranking of the alternatives and selection of the best one.

An environmental issue such as green supply chain may be some difficulties in interpreting the results derived from the typical AHP approach. In addition, the AHP eigenvalue prioritization approach cannot be used when the decision-makers face a complex and uncertain problem and express their comparison judgments as uncertain ratios [37]. Numerous decision attributes, either subject or objective, need to be considered; and these evaluation processes are always complicated and costly. In order to cope with such uncertain judgments, this paper presents fuzzy decision-making framework for selecting the most suitable green supplier under limited evaluation resources. Using information introduced in the second and third steps, the fourth step deals with (i) computing the priorities of the criteria and sub-criteria and (ii) calculating the priorities of different suppliers with respect to each criteria and sub-criteria by solving a matrix equation that translates the pairwise comparison into weights [38]. We assume that the decision maker has had to select a supplier for green purchasing.

Three main criteria have been chosen for evaluation of alternative suppliers, namely Quality, Cost, and Flexibility, and each main criterion is additionally divided into sub-criteria, namely TQEM and ISO 14000 certification, LC cost and Cleaning cost, and Response and Innovation. Three alternative suppliers have been identified as providing potential green materials/components. The environmental performance goal here is to select a supplier satisfying all criteria in the best way. The solution process is based on the proposed fuzzy modification of the AHP method. The first step in applying the fuzzy AHP is to construct a (three level) hierarchy of alternative suppliers and criteria for assessment as shown in Fig. 1.

VI. ANALYSIS OF GREEN SUPPLIER ASSESSMENT

The questionnaire is constructed using the fuzzy AHP concept. To avoid getting subjective results, interviewees were asked about their standard for each scale, which ranged from 1 to 10, prior to answering the questions. There are five different degrees of evaluation used in this study, namely: equally important, a little important, important, very important, and most important. In the next step of the decision-making process, weights of all criteria and scores of alternative suppliers are derived from fuzzy pairwise comparison matrices of the type (1). We suppose that all pairwise comparison judgments are represented as fuzzy triangular numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, such $u_{ij} > m_{ij} > l_{ij}$.

$$\tilde{A}=\begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} \quad (1)$$

where $\tilde{a}_{ij} = 1/\tilde{a}_{ij}$.

The fuzzy comparison judgments with regard to the overall goal are shown in Table 1. From Table 1 it is seen that Quality is considered as the most important criterion, since all fuzzy numbers in the first row are greater than one. For example, Quality is assessed as being about three times more important than Cost and about two times more important than Flexibility.

The maximum rule is applied to solve decision-making problem in an uncertain environment [39]. Therefore, there is always a priority vector $w=(w_1,..,w_n)^T$ in Q^{n-1} that has a maximum degree of membership λ:

$$\lambda = \mu_p(w) = \max \min_{w\in Q^{n-1}} \{\mu_{ijk}(w)\} \quad (2)$$

It is well known that a maximin optimization problem of the type (2) can be represented as the following type (3) [39, 40].

maximize λ subject to

$$\lambda \le \mu_{ijk}(w) \quad (3)$$

As for the decision-maker's satisfaction with different crisp solution ratios w_i/w_j, each crisp priority vector w satisfies the double-side inequality (4) with some degree, which can be measured by a membership function, linear with respect to the unknown ratio w_i/w_j.

$$l_{ij} \tilde{\le} \frac{w_i}{w_j} \tilde{\le} u_{ij} \quad (4)$$

$$\mu_{ij}\left(\frac{w_i}{w_j}\right)=\begin{cases} \dfrac{(w_i - w_j) - l_{ij}}{m_{ij} - l_{ij}}, & \dfrac{w_i}{w_j} \le m_{ij} \\ \dfrac{u_{ij} - (w_i - w_j)}{u_{ij} - m_{ij}}, & \dfrac{w_i}{w_j} \ge m_{ij} \end{cases}. \quad (5)$$

Table 1 Fuzzy pairwise comparisons of the main criteria

Organizational Performance	Quality	Cost	Elasticity
Quality	(1, 1, 1)	(2, 3, 4)	(1, 2, 3)
Cost	(1/4, 1/3, 1/2)	(1, 1, 1)	(1/3, 1/2, 1)
Flexibility	(1/3,1/2,1)	(1, 2, 3)	(1, 1, 1)

The membership function (5) is linearly increasing over the interval (-∞, m_{ij}) and linearly decreasing over interval (m_{ij}, ∞). The above function takes negative values when $w_i/w_j<l_{ij}$ or $w_i/w_j<u_{ij}$ and has a maximum value u_{ij}=1 at $w_i/w_j= m_{ij}$. Over the range (l_{ij}, u_{ij}), the membership function (5) coincides with the fuzzy triangular judgment $\tilde{a}$=(l_{ij}, m_{ij}, u_{ij}).

The maximum prioritization problem can be represented in the following way:

maximize λ subject to

$$\lambda \le \mu_{ij}(w),$$
$$i = 1,\ 2,\dots,\ n-1,\ \ j = 2,\ 3,\dots,\ n,\ \ j > i,$$
$$\sum_{l=1}^{n} w_l = 1,\ w_l > 0,\ l = 1,\ 2,\dots,\ n. \quad (6)$$

Considering the specific form of the membership functions (5), the problem (6) can be further transformed into a bilinear program of the type (7).

maximize λ subject to

$$(m_{ij} - l_{ij})\lambda w_j - w_j + l_{ij} w_j \le 0$$
$$(u_{ij} - m_{ij})\lambda w_j + w_j - u_{ij} w_j \le 0 \quad (7)$$

Where $\sum_{k=1}^{n} w_k = 1,\ w_k > 0,\ k=1, 2, ..., n,\ i = 1,\ 2,\ ...,\ n-1,$ $j = 2,\ 3,\ ...,n,\ j > i.$

VII. THE RESULTS OF ANALYSIS

To obtain crisp weights of these criteria, a non-linear program of the type (4) with one equality and six inequality constraints is solved. The weights of the main criteria thus obtained are:

v_1 = 0.43 (Quality),

v_2 = 0.37 (Cost),

v_3 = 0.20 (Flexibility).

The ratios of the obtained weights are $v1/ v2$ = 1.16, $v1/ v3$ = 2.15, $v2/ v3$ = 1.85, so all initial fuzzy judgments are approximately satisfied. The desired comparison ratio (corresponding solution ratio) between the Quality and Cost is 1.16 as seen from Table 1. On the other hand, the obtained solution ratios are such that $\lambda = \mu 12 = \mu 13 = \mu 23$ = 0.776, therefore, all comparison judgments are equally satisfied with the solution.

Table 2 Second level comparison matrices

Quality	TQM	ISO 14000 certification
TQEM	(1,1,1)	(1,2,3)
ISO 14000 certification	(1/3,1/2,1)	(1,1,1)
Cost	LC cost	Cleaning cost
LC cost	(1,1,1)	(2,3,4)
Cleaning cost	(1/4,1/3,1/2)	(1,1,1)
Flexibility	Innovation	Response
Innovation	(1,1,1)	(4,5,6)
Response	(1/6,1/5,1/4)	(1,1,1)

The positive value of the consistency index λ = 0.776 indicates that the fuzzy judgments are relatively consistent, which is also seen from the above solution ratios. Comparing all sub-criteria at the second level of hierarchy with respect to the upper level elements, the following two-dimensional fuzzy comparison matrices have been constructed (Table 2).

It should be noted that the two-dimensional fuzzy comparison matrices are always consistent. Indeed, in all above cases, the solution ratios are equal to the means of the comparison judgments, and the consistency index takes its maximum value λ = 1. By applying the fuzzy preference programming (FPP) method, the relative weights of all sub-criteria are derived:

v11 = 0.567 (TQEM),

v12 = 0.433 (ISO 14000 certification),

v21 = 0.725 (LC cost),

v22 = 0.275 (Cleaning cost),

v31 = 0.846 (Innovation),

v32 = 0.154 (Response).

The numerical values of the comparison judgments in Table 2 are specially chosen to illustrate comparison matrices with different degrees of inconsistency. The three possible suppliers are further compared with respect to the sub-criteria. The corresponding fuzzy pairwise comparison matrices are shown in Table 3.

By solving a number of optimization problems of a type similar to the first one, we can find the scores of the alternative suppliers with respect to all criteria, which are shown in Table 3. The local weights of all sub-criteria, shown in the second column of Table 3, are obtained by multiplying their relative weights by the weights of the main criteria. The value of the consistency index for each optimal solution is shown in the last column of the table. From this column we can see that the fuzzy comparison matrices with respect to TQEM and Response are absolutely consistent. In this case, the solution ratio for all scores coincides with the means of the fuzzy judgments.

Table 3 Fuzzy pairwise comparison for the alternative providers

	Supplier1	Supplier2	Supplier3
TQEM			
Supplier1	(1,1,1)	(1, 2, 3)	(6, 7, 8)
Supplier2	(1/4, 1/3,1/2)	(1,1,1)	(4, 5, 6)
Supplier3	(1/8, 1/7, 1/6)	(1/6, 1/5, 1/4)	(1,1,1)
ISO 14000 Certification			
Supplier1	(1,1,1)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)
Supplier2	(1, 2, 3)	(1,1,1)	(1/3, 1/2, 1)
Supplier3	(3, 4, 5)	(1, 2, 3)	(1,1,1)
LC cost			
Supplier1	(1,1,1)	(1/5, 1/4, 1/3)	(1/7, 1/6, 1/5)
Supplier2	(3, 4, 5)	(1,1,1)	(2, 3, 4)
Supplier3	(5, 6, 7)	(4, 5, 6)	(1,1,1)
Cleaning cost			
Supplier1	(1,1,1)	(1/6, 1/5, 1/4)	(1/4, 1/3, 1/2)
Supplier2	(4, 5, 6)	(1,1,1)	(3, 4, 5)
Supplier3	(2, 3, 4)	(1/4, 1/3, 1/2)	(1,1,1)
Innovation			
Supplier1	(1,1,1)	(1/2, 1, 2)	(2, 3, 4)
Supplier2	(1/2, 1, 2)	(1,1,1)	(4, 5, 6)
Supplier3	(1/4, 1/3, 1/2)	(1/6, 1/5, 1/4)	(1,1,1)
Response			
Supplier1	(1,1,1)	(1, 2, 3)	(5, 6, 7)
Supplier2	(1/3, 1/2, 1)	(1,1,1)	(2, 3, 4)
Supplier3	(1/7, 1/6, 1/5)	(1/4, 1/3, 1/2)	(1,1,1)

Table 4 Results from the Fuzzy AHP method

	Criteria weights	S1	S2	S3	λ
TQEM	0.277	0.621	0.310	0.078	0
ISO14000 certification	0.179	0.145	0.282	0.567	1
LC cost	0.172	0.087	0.205	0.706	-0.914
Cleaning cost	0.061	0.114	0.616	0.264	0.403
Innovation	0.224	0.387	0.502	0.110	0.531
Response	0.087	0.605	0.301	0.099	1
Aggregated weights		0.359	0.348	0.294	

For example, the solution ratios for Response are r12 = 0.6/0.3 = 2; r13 = 0.6/0.1 = 6; r23 = 0.3/0.1 = 3, which ratios are equal to the means of the corresponding fuzzy comparison judgments in Table 4.

Since the value of the consistency index for TQEM, shown in the fourth raw of Table 4 is negative, it follows that the corresponding comparison matrix is strongly inconsistent. In fact, the comparison ratios in this case are r12 = 0.087/0.205 = 0.424; r13 = 0.087/0.706 = 0.123; r23 = 0.205/0.706 = 0.290, which are correspondingly outside the scopes of the fuzzy judgments (0.2-0.333), (0.143-0.2), and (0.167-0.25). The remaining comparison matrices in Table 4 are weakly inconsistent, since the consistency index is non-negative. The second row of Table 4 shows that the value of consistency index for TQEM comparison matrix is equal to zero. This illustrates a case where the fuzzy comparison judgments are satisfied just at their boundaries. It is readily seen that in this case the score ratios are r12 = 0.621/0.310 = 2, r13 = 0.621/0.078 = 8, r23 = 0.310/0.078 = 4.

The combination of priority weights for sub-criteria, criteria, and alternatives, to determine priority weights for the best catering firm, are given in Table 4. In this case, the aggregated weights show that the first supplier (0.359) is slightly better than the second one (0.348), while the third supplier is ranked last (0.294).

VIII. DISCUSSION AND CONCLUSION

In other words, an assessment of a supplier's impact on the state of operational stages (product design, procurement, manufacturing/assembly, logistics, packing, and distribution) allows an manufacturer to verify how it performs with respect to environmental friendly practices and environmental performance.

There is no difference among the assemblers, direct suppliers, and indirect suppliers are found in regard to the importance placed on technological innovation and environmental issue [41]. Consequently, the need to continuously improve corporate environmental performance will force firms to involve suppliers in their environmental programs connected to operational stages.

This study of green supplier assessment addresses actual environmental performance through fuzzy AHP analysis. The findings indicate that selecting first-tier or second-tier suppliers based on the potential of Quality, Cost, and Flexibility is very important for improving the environmental performance of communication equipment companies. That is, Quality, Cost, and Flexibility are important selection items, regardless of the position in the supply chain. In this empirical study, we recognize Quality is more important than Cost and Flexibility when viewed by purchasing decision-makers. In addition, most decision-makers aware of TQEM, LC cost, and Innovation are highly significant than ISO 14000, Cleaning, and Response. In other cases, we may get different results because of decision-makers' preferences and subjective judgments.

This simplified example is chosen for illustration only. In fact, the proposed fuzzy AHP approach can be used to solve any large-scale selection problem that might occur in practice. However, the hierarchical structure of green supplier assessment has implication for adopters of green supply chain management practices.

In the recent years, South Africa's government and enterprises more and more emphasize the integrated environmental management (IEM). IEM is designed to ensure that the environmental impacts and implications of proposals (including policies, programs, plans, and projects) are investigated and adequately considered in the planning and decision-making process [42]. This article provides a managerial perspective contributed to environmental innovation.

On the whole, suppliers/assemblers place a higher level of importance on environmental technology and innovation. In light of these issues, manufacturers implementing a pro-active green strategy must consider a supplier's environmental performance. Firms need to verify whether the supplier will be able to work with them to carry out new green supply chain management. Overall, the results of this paper emphasize the importance of assessment methodologies that allow a purchasing team to select only eco-efficient suppliers.

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